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**Dennison et al.**

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(54) **METHOD OF MAKING FIELD EFFECT TRANSISTORS**

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(73) Assignee: **Micron Technology, Inc.**, Boise, ID (US)

(\* ) Notice: This patent issued on a continued prosecution application filed under 37 CFR 1.53(d), and is subject to the twenty year patent term provisions of 35 U.S.C. 154(a)(2).

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Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **08/708,489**

(22) Filed: **Sep. 5, 1996**

**Related U.S. Application Data**

(62) Division of application No. 08/132,705, filed on Oct. 6, 1993, now abandoned.

(51) **Int. Cl.**<sup>7</sup> ..... **H01L 21/84**

(52) **U.S. Cl.** ..... **438/161; 438/286; 438/300**

(58) **Field of Search** ..... 437/21, 40-41; 438/300, 151, 161, 157, 286

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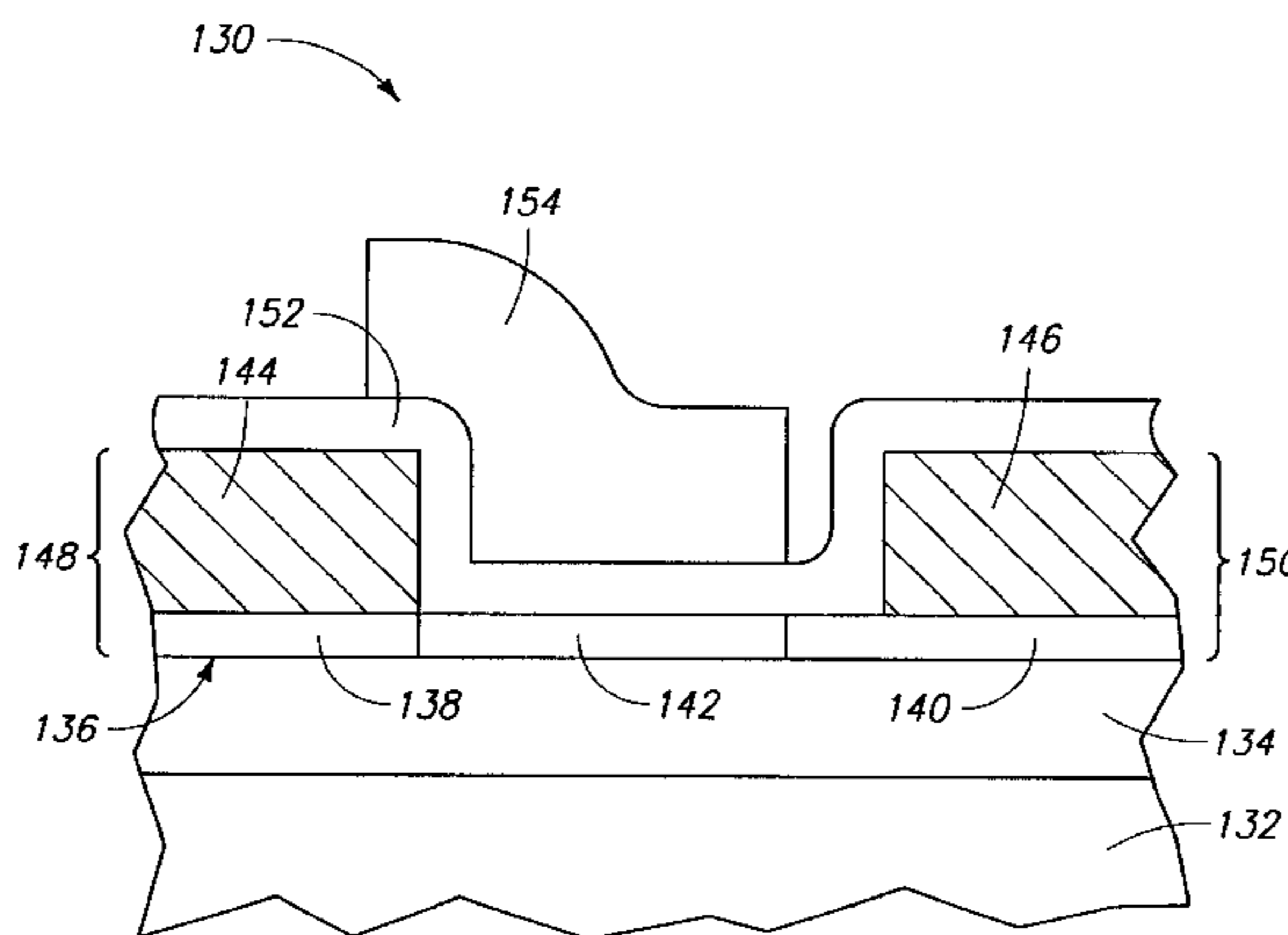
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(57) **ABSTRACT**

A thin film field effect transistor includes: a) a thin film channel region; b) a pair of opposing electrically conductive first and second source/drain regions adjacent the thin film channel region; c) a gate insulator and a gate positioned adjacent the thin film channel region for electrically energizing the channel region to switch on the thin film field effect transistor; d) the first source/drain region having a first thickness, the second source/drain region having a second thickness, the channel region having a third thickness; at least one of the first and second thicknesses being greater than the third thickness. Methods are disclosed for making thin field effect transistors.

**6 Claims, 11 Drawing Sheets**



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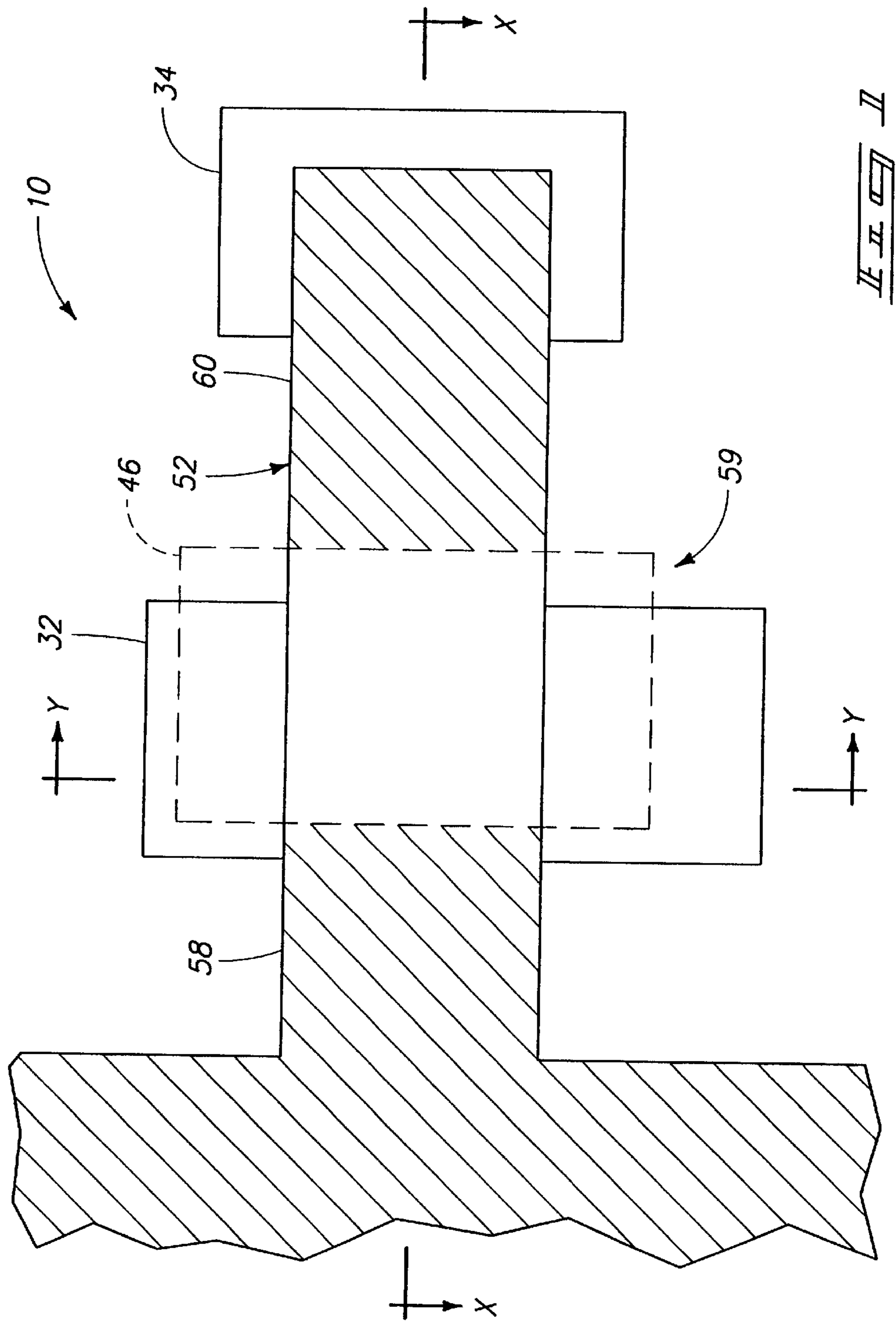
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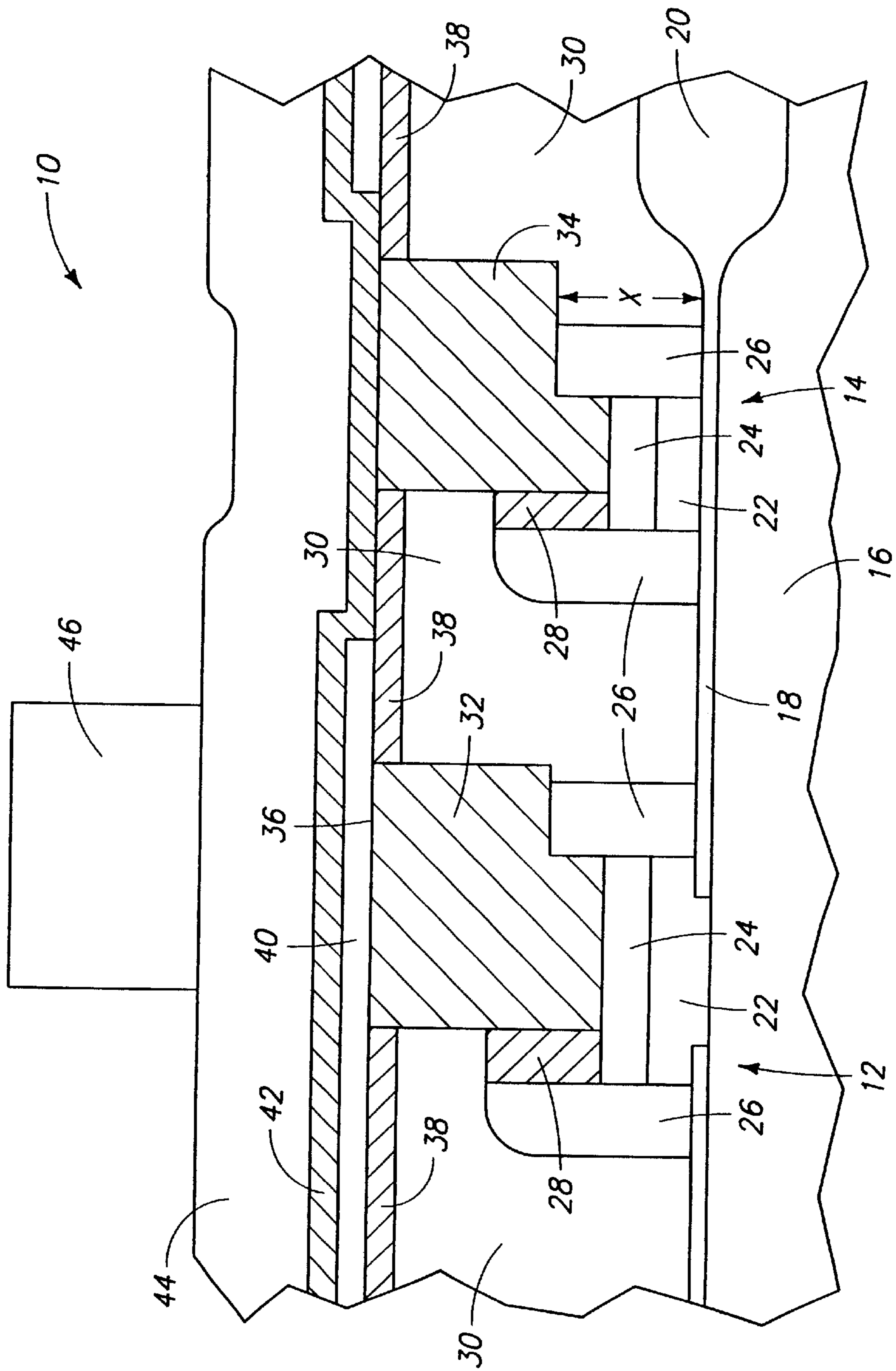
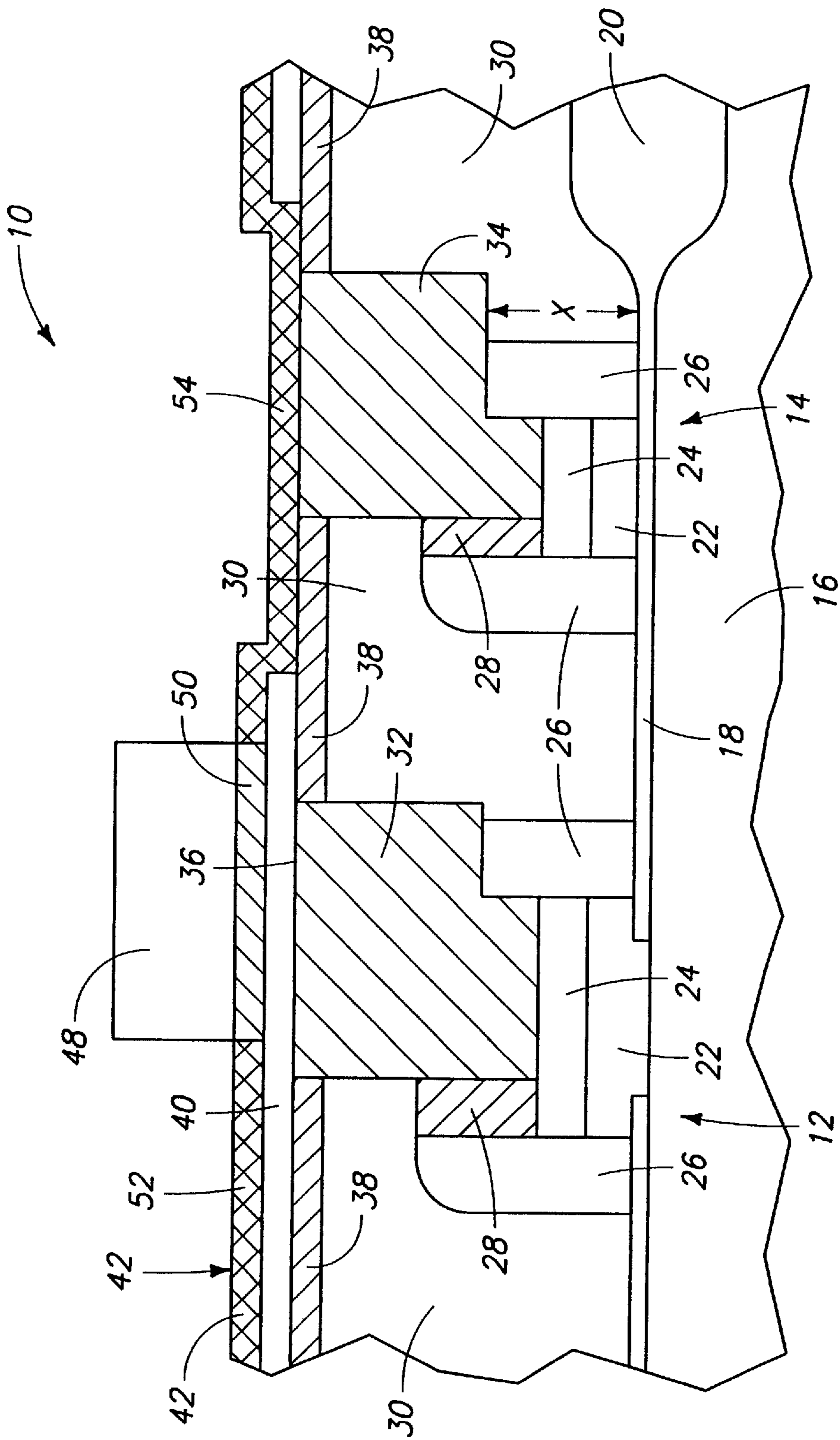


FIG. 2







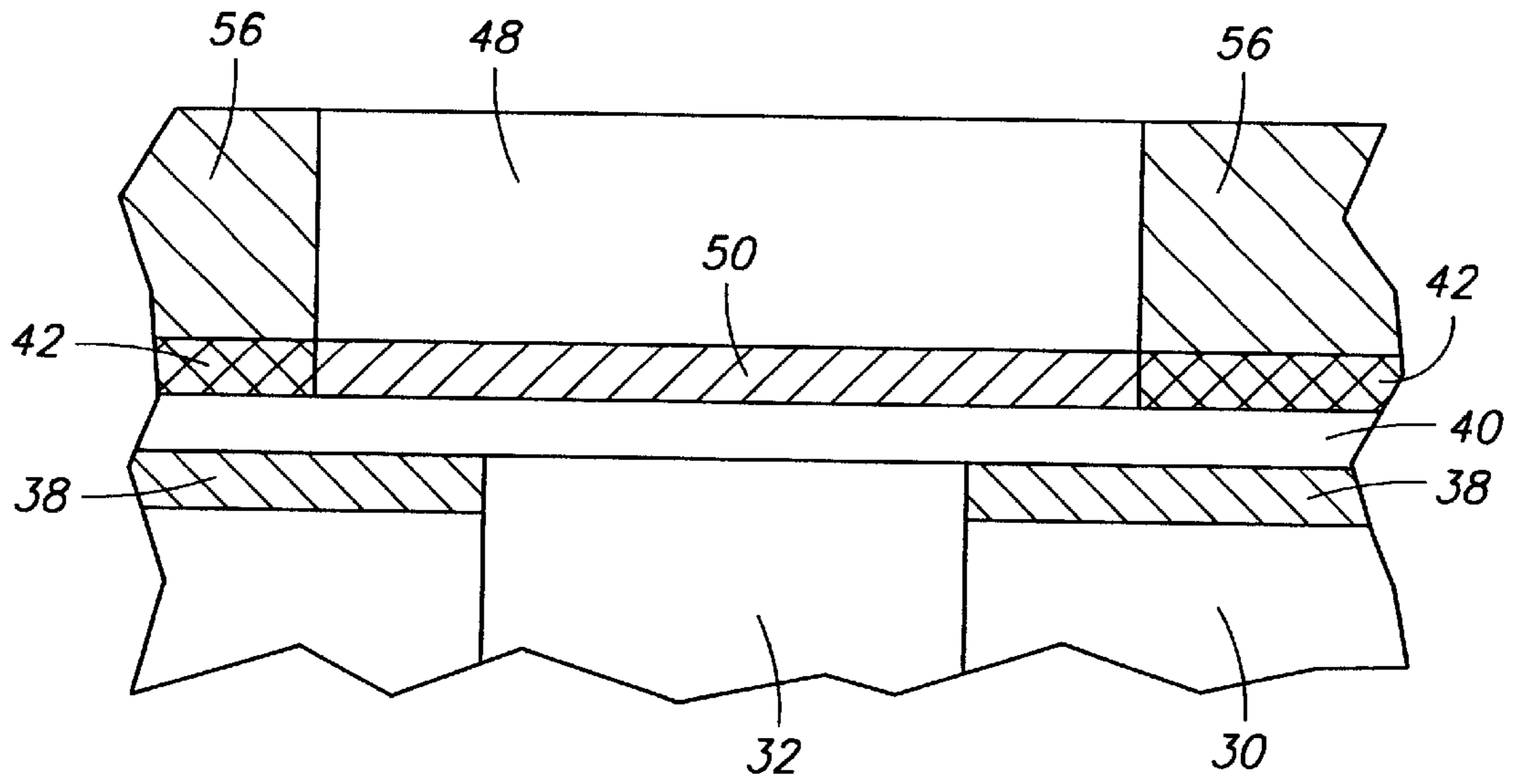


FIG. 6

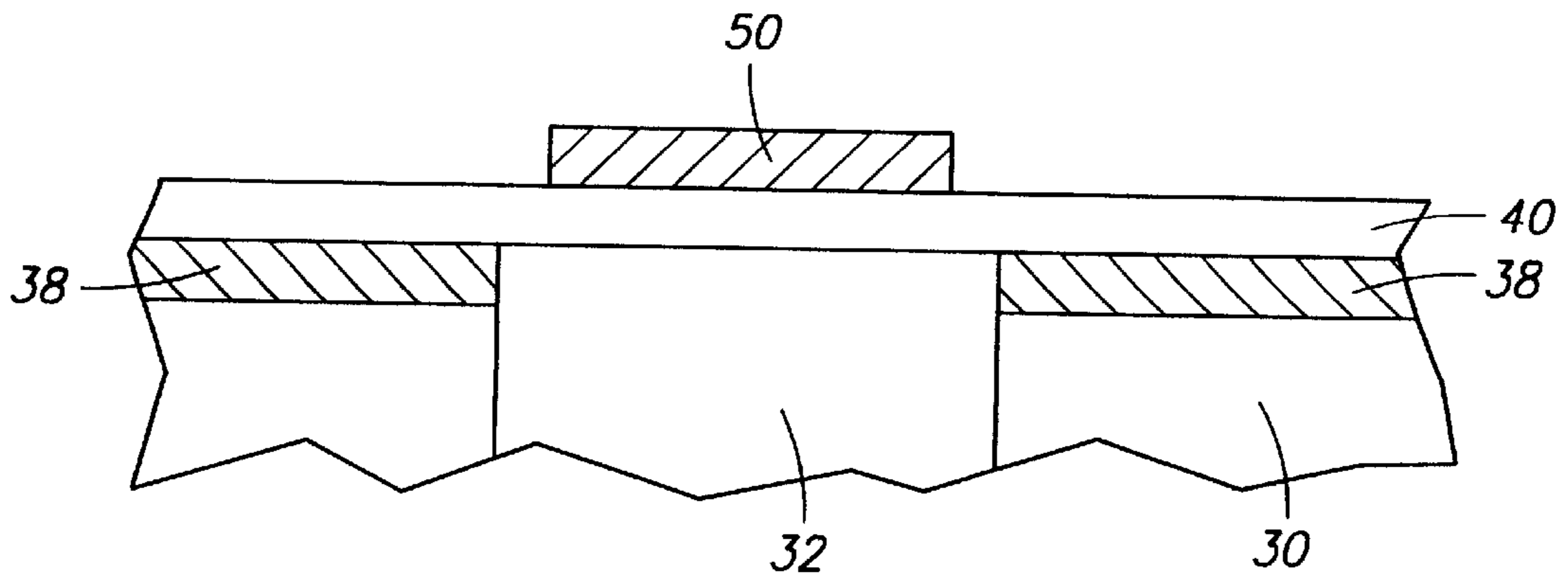


FIG. 7



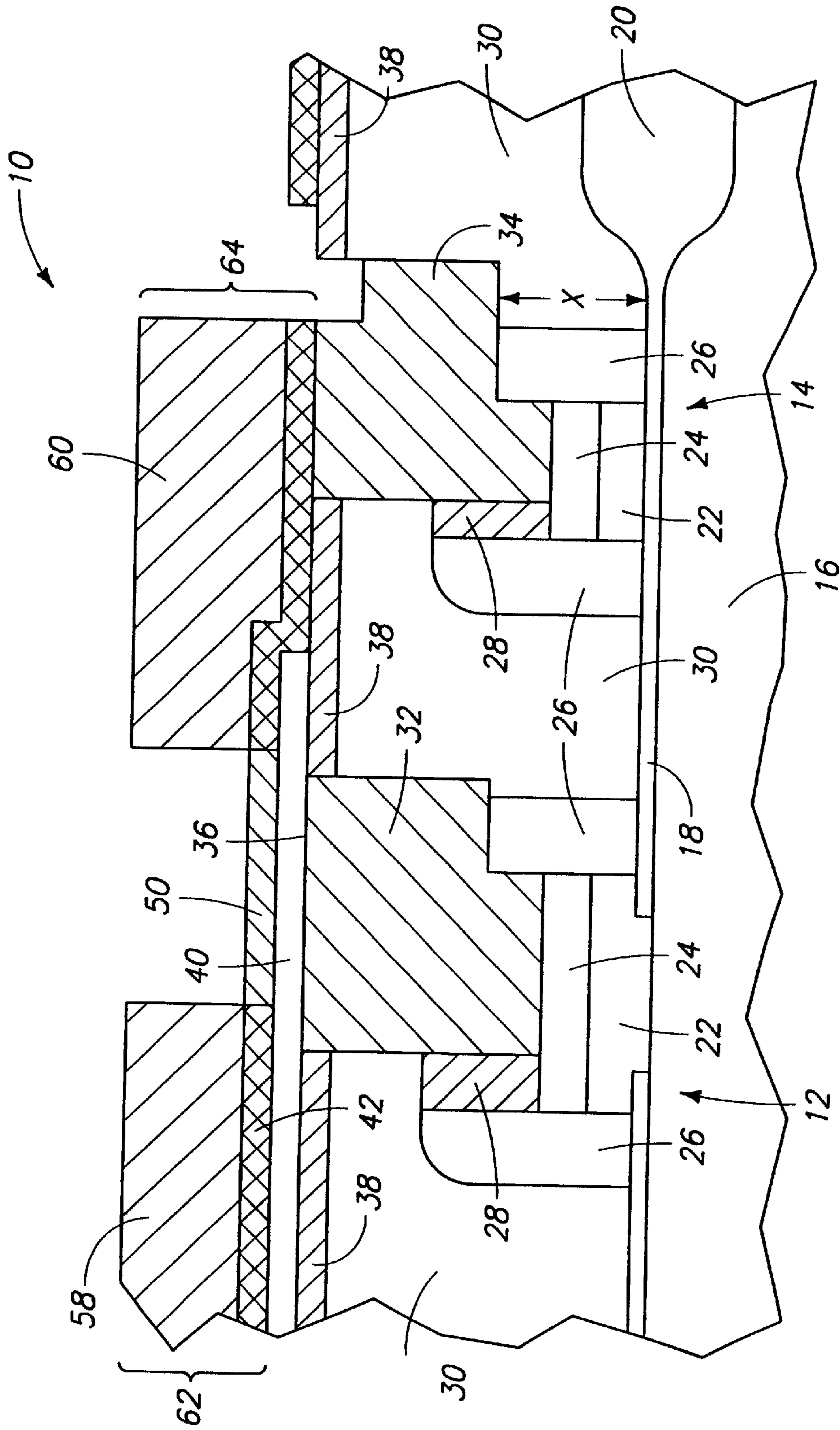


FIG. 7

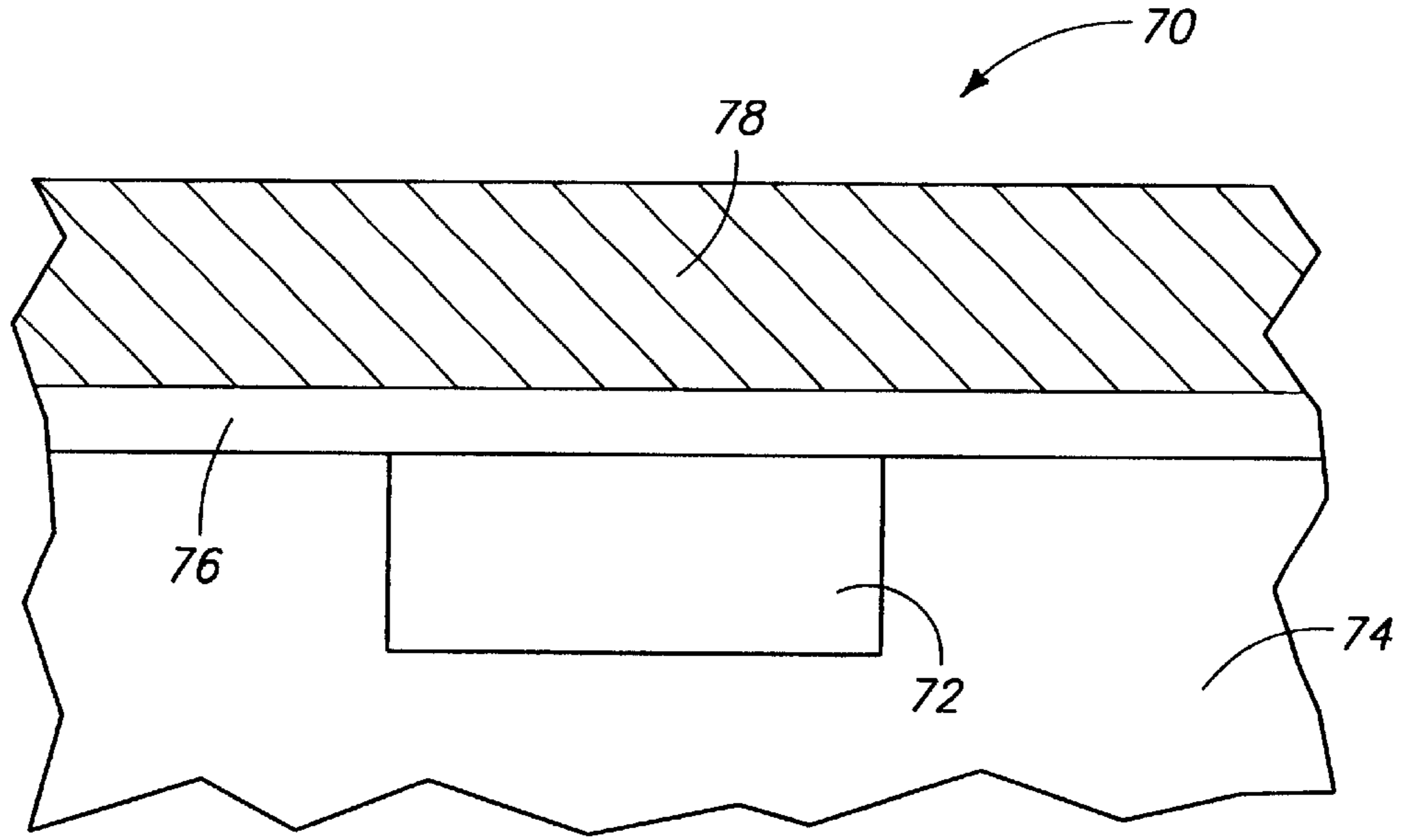


FIG. 9

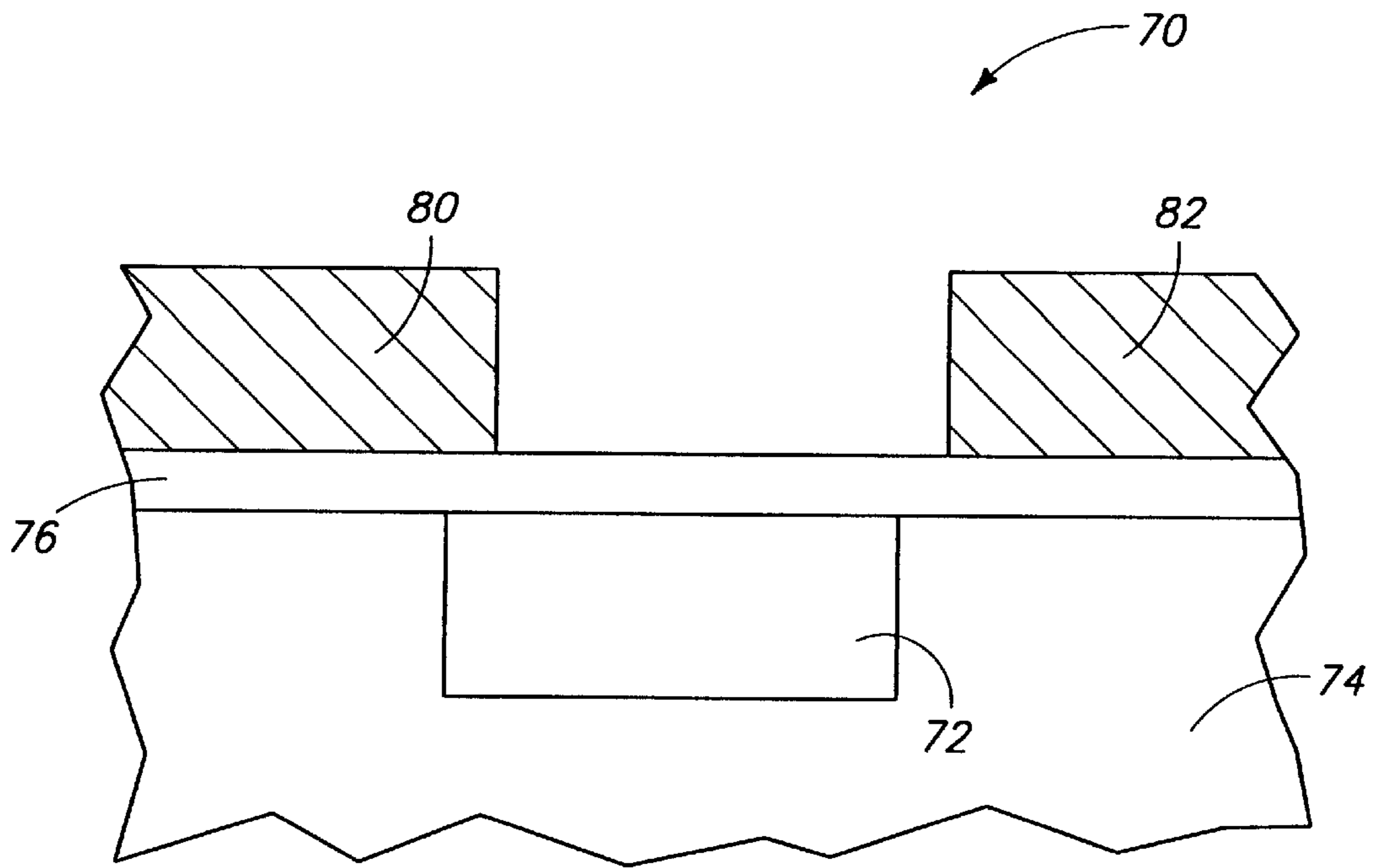
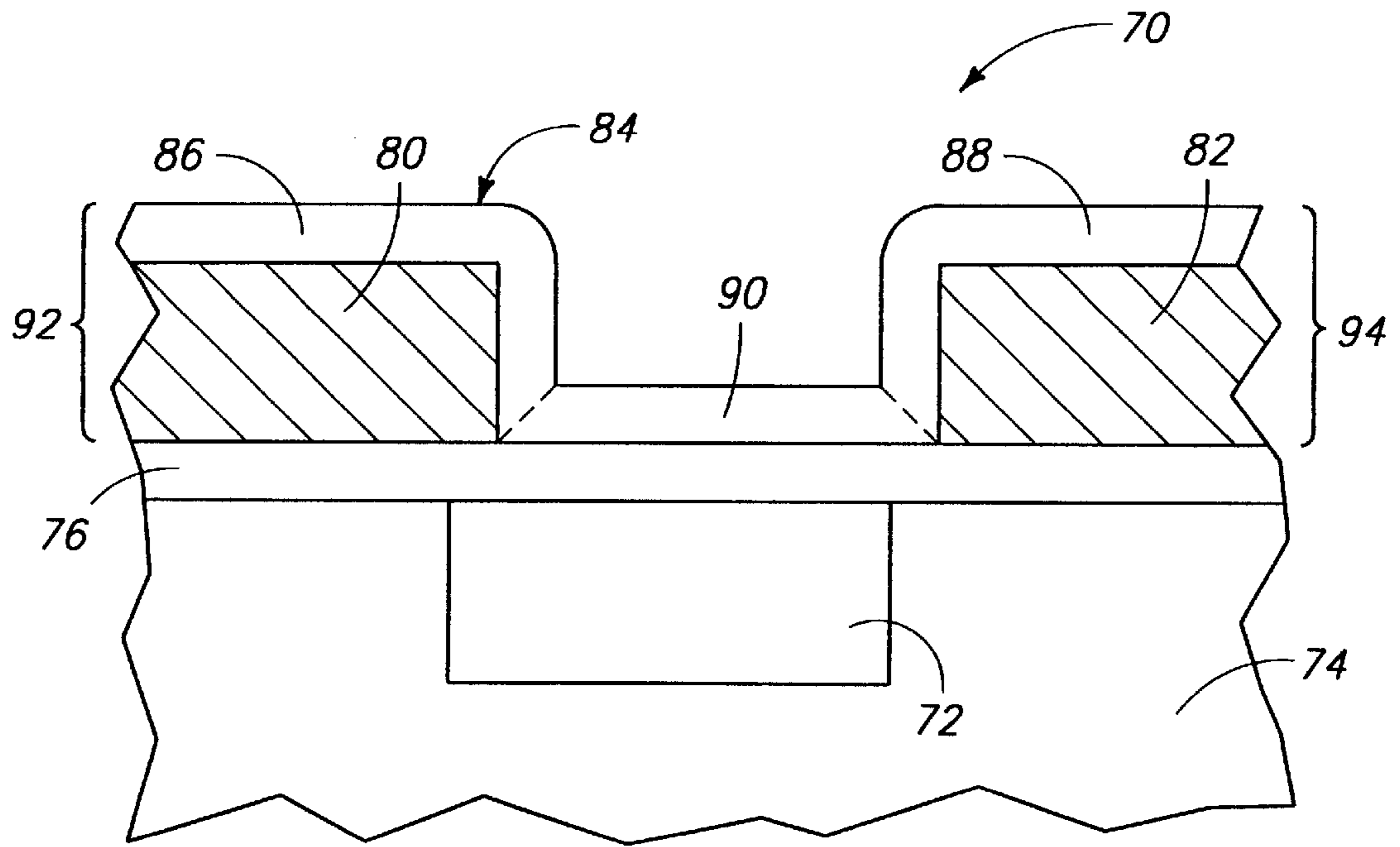
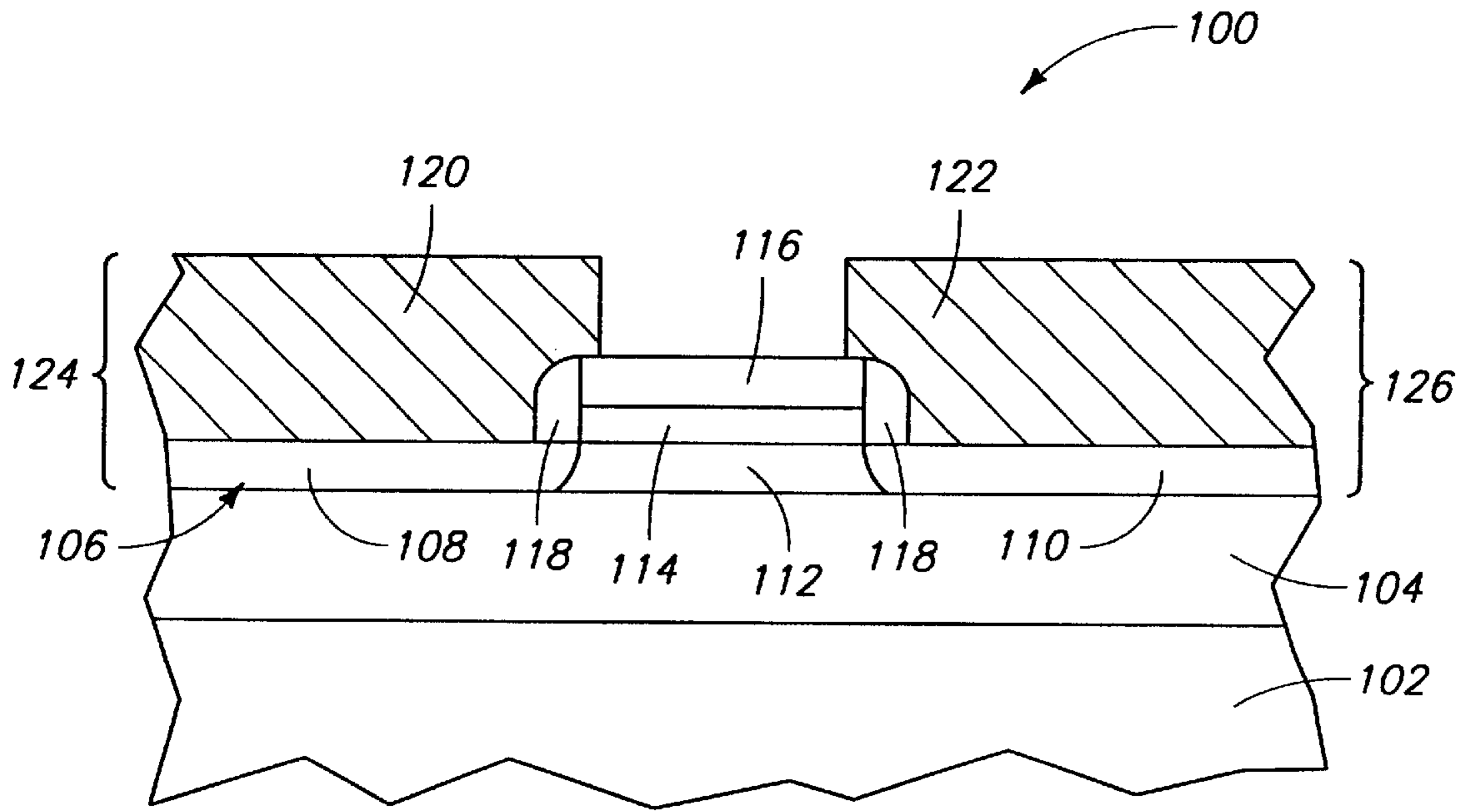


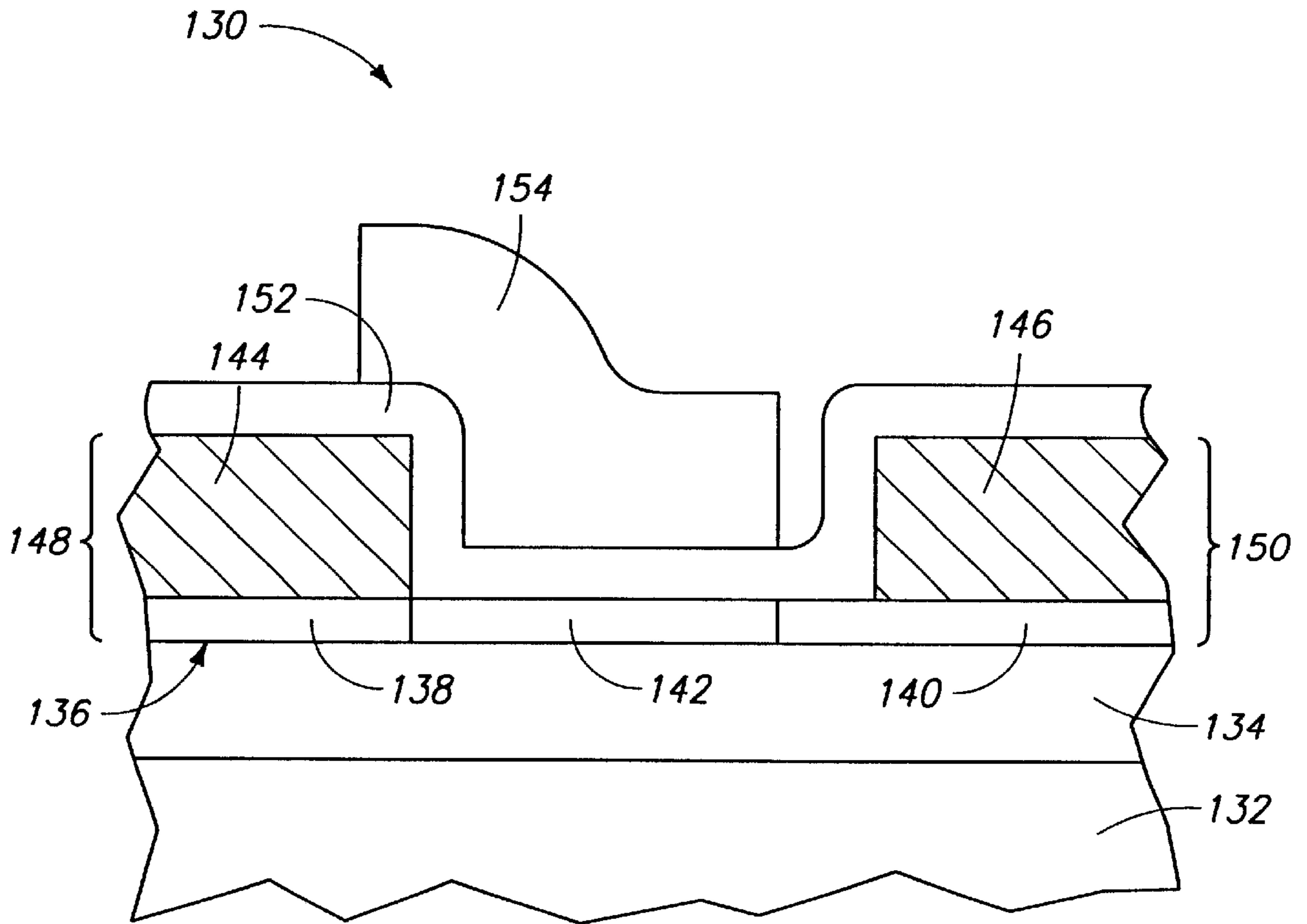
FIG. 10



II II II II



II II II II



*FIG. 10*

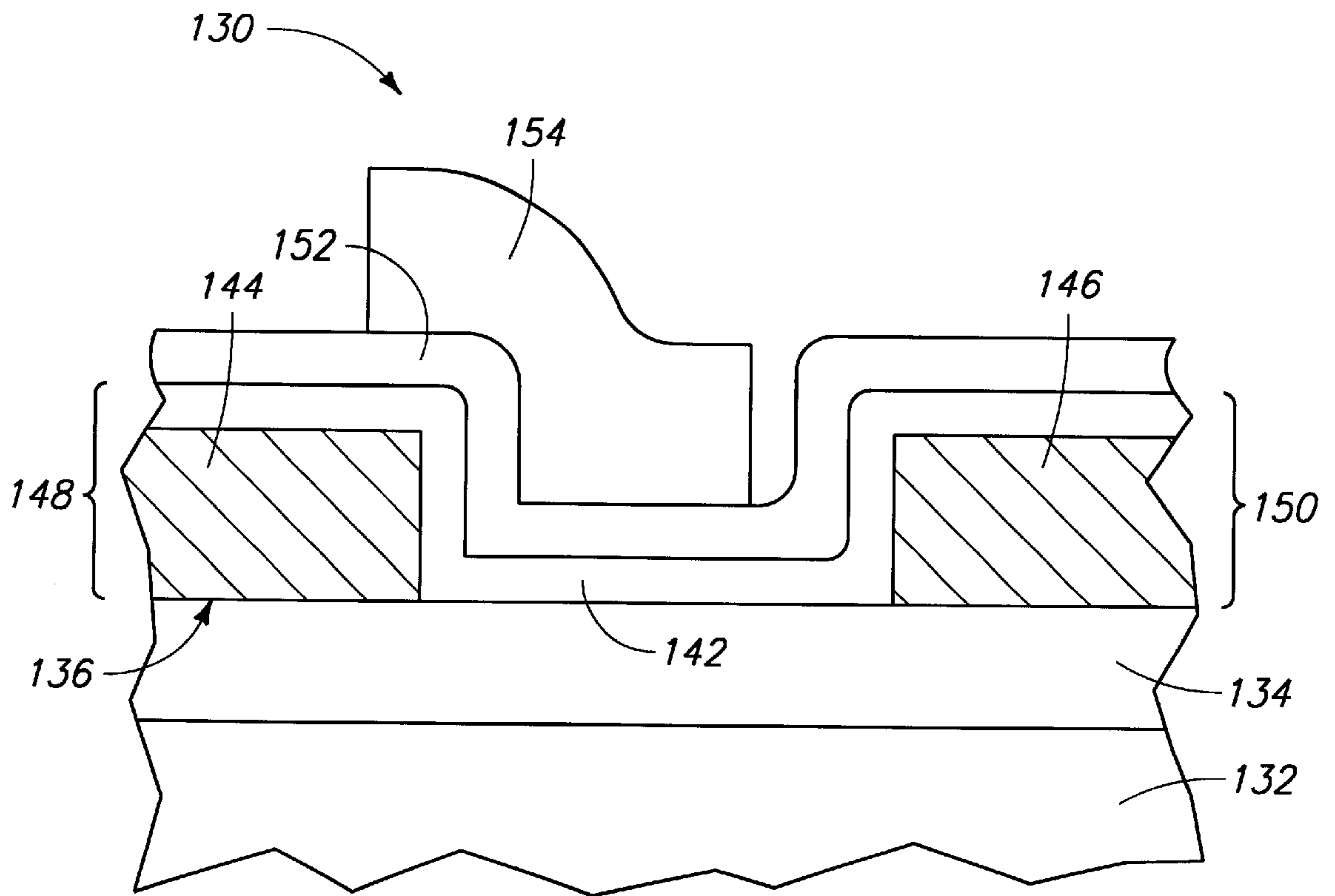


FIG. 11

## METHOD OF MAKING FIELD EFFECT TRANSISTORS

### RELATED PATENT DATA

This patent resulted from a divisional application of U.S. patent application Ser. No. 08/132,705, filed on Oct. 6, 1993, and now abandoned entitled "Thin Film Transistors and Method of Making" listing the inventor as Charles H. Dennison and Monte Manning.

This invention was made with Government support under Contract No. MDA972-92-C-0054 awarded by Advanced Research Projects Agency (ARPA). The Government has certain rights in this invention.

### TECHNICAL FIELD

This invention relates specifically to film transistor technology.

### BACKGROUND OF THE INVENTION

As circuit density continues to increase, there is a corresponding drive to produce smaller and smaller field effect transistors. Field effect transistors have typically been formed by providing active areas within a bulk substrate material or within a complementary conductivity type well formed within a bulk substrate. One recent technique finding greater application in achieving reduced transistor size is to form field effect transistors with thin films, which is commonly referred to as "thin film transistor" (TFT) technology.

With TFTs, a substantially constant thickness thin film of material (typically polysilicon) is first provided. A central channel region of the thin film is masked, while opposing adjacent source/drain regions are doped with an appropriate p or n type conductivity enhancing impurity. A gate insulator and gate is provided either above or below the thin film channel region, thus providing a field effect transistor having active and channel regions formed entirely within a thin film as opposed to a bulk substrate.

In TFT technology, one goal is to provide the thin film as thin as possible to produce a thin channel region which provides maximized desired on/off characteristics for the transistors. Such, however, adversely affects source/drain region conductance due to diminished volume of material, thus resulting in undesirable elevated  $V_{cc}$  source/drain resistance.

It would be desirable to improve upon methods of forming thin film transistors and in improving thin film transistor constructions.

### BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the invention are described below with reference to the following accompanying drawings.

FIG. 1 is a top diagrammatic plan view of a substantially completed portion of a semiconductor substrate provided with a thin film transistor in accordance with the invention.

FIG. 2 is a view of a semiconductor wafer fragment taken at one processing step in accordance with the invention, and positionally corresponds with an X—X line cut through the FIG. 1 plan view, but is taken at a point in time before all the components represented by FIG. 1 have been produced.

FIG. 3 is a view of the FIG. 2 wafer fragment shown at a processing step subsequent to that shown by FIG. 2.

FIG. 4 is a view of the FIG. 2 wafer fragment shown at a processing step subsequent to that shown by FIG. 3.

FIG. 5 is a view of the FIG. 2 wafer fragment shown at a processing step subsequent to that shown by FIG. 4.

FIG. 6 is a view of the FIG. 2 wafer fragment corresponding in processing sequence to the step shown by FIG. 5, but positionally corresponding with a Y—Y line cut relative to FIG. 1.

FIG. 7 is a diagrammatic section of the FIG. 2 semiconductor wafer taken at a processing step subsequent to that shown by FIG. 5, and positionally representing an X—X cut.

FIG. 8 is a view of the FIG. 7 wafer showing a Y—Y positional cut.

FIG. 9 is a sectional view of an alternate semiconductor wafer fragment processed in accordance with alternate aspects of the invention.

FIG. 10 is a view of the FIG. 9 wafer taken at a processing step subsequent to that shown by FIG. 9.

FIG. 11 is a sectional view of the FIG. 9 wafer taken at a processing step subsequent to that shown by FIG. 10.

FIG. 12 is a diagrammatic sectional view of a further alternate semiconductor wafer fragment processed in accordance with further alternate methods in accordance with the invention.

FIG. 13 is a diagrammatic sectional view of still a further alternate embodiment semiconductor wafer fragment processed in accordance with still further alternate techniques in accordance with the invention.

FIG. 14 is a diagrammatic sectional view of yet another alternate embodiment semiconductor wafer fragment processed in accordance with further alternate methods in accordance with the present invention.

### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

This disclosure of the invention is submitted in furtherance of the constitutional purposes of the U.S. Patent Laws "to promote the progress of science and useful arts" (Article 1, Section 8).

In accordance with one aspect of the invention, a method of forming a thin film field effect transistor comprises the following steps:

- 40 providing a transistor gate;
- providing a thin film transistor layer comprising first and second source/drain areas separated by an intervening thin film channel region, the thin film channel region being gated by the transistor gate through a gate insulator, the thin film transistor layer having a selected thickness;
- 45 providing a layer of electrically conductive material adjacent the thin film transistor layer;
- patterning and etching the electrically conductive material to define first and second source/drain blocks; and
- 50 the first and second source/drain blocks electrically interconnecting with the respective thin film first and second source/drain areas to define composite first and second source/drain regions having thickness which is greater than the thin film layer thickness.

In accordance with another aspect of the invention, a thin film field effective transistor comprises:

- 55 a thin film channel region;
- a pair of opposing electrically conductive first and second source/drain regions adjacent the thin film channel region;
- 60 a gate insulator and a gate positioned adjacent the thin film channel region for electrically energizing the channel region to switch on the thin film field effect transistor;
- the first source/drain region having a first thickness, the second source/drain region having a second thickness, the channel region having a third thickness; at least one of the first and second thicknesses being greater than the third thickness.
- 65

Referring first to FIGS. 1–8 and initially to FIG. 2, there illustrated is a semiconductor wafer fragment indicated generally by reference numeral 10. Such illustrates but one portion of a static random access memory (SRAM) cell employing a pair of pull down transistor gates 12 and 14. Such are provided over a bulk semiconductor substrate 16 including an associated gate oxide layer 18 and field oxide region 20. Pull down gates 12 and 14 each comprise conductive polysilicon regions 22 which may be capped with higher conductive material regions 24, such as  $WSi_x$ . Pull down gates 12 and 14 are also provided with oxide sidewall spacers 26 and nitride caps 28. An insulating layer 30, typically borophosphosilicate glass (BPSG), surrounds or otherwise encapsulates pull down gates 12 and 14. Electrically conductive polysilicon plugs 32 and 34 are provided over pull down gates 12 and 14 to electrically connect with the upper surface of the respective regions 24. For purposes of the continuing discussion, conductive poly plug 32 has an upper surface 36. BPSG layer 30 is capped with a  $Si_3N_4$  layer 38.

Conductive polysilicon plug 32 in accordance with the invention is utilized as a transistor gate for a thin film transistor, and more specifically in this described embodiment comprises a bottom gate for producing a bottom gated thin film transistor. FIG. 1 also illustrates an outline 32 representative of the size and shape of the thin film transistor gate. As depicted, at least local planarizing in the vicinity of bottom gate 32 (FIG. 2) has been conducted to provide upper bottom gate surface 36 in a substantially planar form. Planar surface 36 is substantially co-planar with adjacent upper surfaces, such as the upper surfaces of nitride layer 38. A preferred technique for producing the construction as described to this point is disclosed and provided in our U.S. patent application Ser. No. 08/061,402, filed on May 12, 1993, and entitled “Fully Planarized Thin Film Transistor (TFT) And Process To Fabricate Same”.

A gate insulator layer 40, preferably  $SiO_2$ , is provided and patterned as shown. An example thickness would be 300 Angstroms. A thin film transistor layer 42 is provided thereatop. Such preferably comprises polysilicon provided to a thickness of from about 100 Angstroms to about 350 Angstroms. This could be provided by polysilicon deposition, or by deposition of an amorphous silicon followed by a crystallization technique, such as solid phase crystallization.

A masking layer 44, typically  $SiO_2$ , is deposited to a thickness of about 2,000 Angstroms. Material of layer 44 might ultimately be sacrificial, or portions thereof remain permanently on the wafer. A preferred technique as described below is to utilize all the material of layer 44 ultimately as sacrificial material, such that its composition from an electrically conductive/non-electrically conductive standpoint is immaterial. If the material of layer 44 is ultimately to remain on the produced wafer, it will be provided to be electrically non-conductive to provide satisfactory thin film transistor operation. An example of another material usable for layer 44 is polyimide.

A layer of photoresist is provided, and patterned to produce a masking block 46. The outline of masking block 46 is also viewable in FIG. 1.

Referring to FIG. 3, masking block 46 has been utilized during an etch of layer 44 to produce an oxide masking block 48 relative to underlying thin film transistor layer 42. Such covers and defines a thin film channel region 50 as well as first and second opposing source drain areas 52, 54 separated by intervening thin film channel region 50. Oxide mask 48 also upwardly exposes first and second source/drain areas 52, 54, respectively. Thin film transistor layer 42 is preferably conductively doped with a p+ impurity at this point in the process, thus rendering source/drain areas 52

and 54 electrically conductive. Thus, thin film channel region 50 is gateable by bottom transistor gate 32 through gate insulating layer 40.

Referring to FIG. 4, a layer 56 of electrically conductive material, preferably ultimately conductively doped polysilicon, is provided atop and thereby adjacent thin film transistor layer 42 and over oxide mask block 48. An example and preferred thickness for layer 56 is 2,000 Angstroms. Polysilicon layer 56 can be in situ conductively doped or doped subsequent to deposition. Such ultimate doping of layer 56 might effectively also desirably provide doping of underlying first and second source/drain areas 52 and 54 respectively, such that 52 and 54 might not previously be required to be doped in a separate doping step.

Referring to FIG. 5, polysilicon layer 56 is chemical-mechanical polished (CMP) to remove polysilicon from about oxide block 48 and provide a substantially globally planarized upper surface. An example CMP step would be to utilize a slurry comprising KOH,  $SiO_2$  particles (silica) and water. FIG. 6 illustrates a FIG. 1 Y—Y positional cut of the wafer at the processing step represented by FIG. 5.

Referring to FIG. 7, oxide block 48 has been wet stripped from the wafer, and polysilicon layer 56 patterned and etched to define first and second source/drain blocks 58 and 60, respectively. FIG. 8 illustrates the Y—Y cut of the wafer at the processing step of FIG. 7, and FIG. 1 as well represents the pattern outline of blocks 58 and 60. As is apparent from at least FIG. 7, first and second source/drain blocks 58, 60 respectively, electrically interconnect with the thin film first and second source/drain areas 52 and 54, respectively. Such defines composite first and second source/drain regions 62, 64 respectively, which have thickness which is greater than the thickness of thin film layer 42 utilized to produce thin film channel region 50.

The above provided method and construction provide a desired advantage of enabling producing a thin film channel region as thin as desirable, while minimizing resistance in source/drain region 62, 64 the result of their greater thickness and thereby greater volume of conductive material for desirable operation of the thus formed thin film transistor.

The invention proceeds with reference to FIGS. 9–11 for description of an alternate embodiment thin film transistor construction and method in accordance with the invention. The FIGS. 1–8 embodiment described a method and construction wherein the thin film transistor layer was provided before the subsequent layer of electrically conductive material was provided and patterned. The embodiment of FIGS. 9–11 shows the opposite, whereby the layer of electrically conductive material is provided and patterned before thin film transistor layer application, and in the context of a bottom-gated thin film transistor. Specifically, FIG. 9 illustrates a semiconductor wafer fragment 70 comprised of a conductive bottom gate 72 formed within a bulk insulating layer 74. A layer 76 of insulating gate dielectric is provided atop insulator 74. A layer 78 of electrically conductive material, preferably polysilicon, is provided atop layer 76.

Referring to FIG. 10, layer 78 has been patterned and etched to produce offset first and second source/drain blocks 80 and 82, respectively.

Referring to FIG. 11, a thin film transistor layer 84 is provided. Such would be patterned and doped to provide first and second respective source/drain areas 86 and 88 respectively, and intervening thin film channel region 90. Thus, such produces first and second source/drain regions 92 and 94 having a thickness which is greater than thin film channel region 90. This is but one example of a bottom-gated film transistor in accordance with the invention wherein the layer of electrically conductive material utilized for producing source/drain blocks is provided and patterned before application of the thin film transistor layer.

FIGS. 12 and 13 illustrate alternate methods and constructions in accordance with the invention employing top gating in a thin film transistor. Referring first to FIG. 12, there illustrated is a semiconductor wafer fragment generally indicated by reference numeral 100. Such comprises a bulk substrate region 102 and overlying planarized oxide layer 104. A thin film channel layer 106 has been provided, and comprises first and second source/drain areas 108 and 110, respectively, separated by an intervening thin film channel region 112. Thereafter, a top gate insulating layer 114 has been deposited and patterned as shown, in conjunction with depositing and patterning of a gate layer for producing top gate 116. Insulating sidewall spacers 118 would be provided as shown. A layer of electrically conductive material is provided, patterned and etched to define first and second source/drain blocks 120 and 122, respectively. First and second source/drain blocks 120 and 122 respectively, electrically interconnect with the respective thin film first and second source/drain areas 108 and 110 to define composite first and second source/drain regions 124 and 126, respectively. Thus, composite first and second source/drain regions 124 and 126 are defined which have thickness greater than the thin film layer thickness utilized to produce transistor channel region 112.

FIG. 13 illustrates an alternate embodiment wafer fragment generally indicated by reference numeral 130. Such is comprised of a bulk substrate 132 and overlying planarized layer 134 of insulating SiO<sub>2</sub>. A thin film transistor layer 136 is provided atop oxide layer 134. Thin film transistor layer 136 is comprised of first and second source/drain areas 138 and 140, respectively, which are separated by an intervening thin film channel region 142. Thereafter, a layer of electrically conductive material (typically polysilicon) is provided over thin film transistor layer 136. Such is patterned and etched to define first and second source/drain blocks 144 and 146, respectively. Thus, such blocks electrically interconnect with the respective thin film first and second source/drain areas 138 and 140, thus defining composite first and second source/drain regions 148 and 150 which have a thickness greater than thin film transistor layer 136 thickness.

Subsequently, a gate dielectric layer 152 is deposited. Then, a conductive top gate layer is deposited and patterned to provide a top gate 154.

In each of the above-described embodiments with respect to FIGS. 12 and 13, a top gate conductor is provided. Alternate embodiments could of course be produced and fall within the scope of the existing invention which is only intended to be limited by the concluding claims. By way of example only as one alternate, top gated thin film transistors in accordance with the invention could also of course be produced by first provision of the source/drain blocks, followed by subsequent provision of the thin film transistor layer thereatop.

In accordance with the above-described embodiments, thin film transistors are provided wherein each of the source/drains are provided to have substantially equal and greater thickness than the thin film channel regions. Alternately in accordance with the invention, a thin film field effect transistor could be provided wherein perhaps only one of the source/drain areas is provided with greater thickness, or each of the source/drain areas provided with greater thickness than the channel region, but of differing thicknesses.

In compliance with the statute, the invention has been described in language more or less specific as to structural and methodical features. It is to be understood, however, that the invention is not limited to the specific features shown and described, since the means herein disclosed comprise

preferred forms of putting the invention into effect. The invention is, therefore, claimed in any of its forms or modifications within the proper scope of the appended claims appropriately interpreted in accordance with the doctrine of equivalents.

What is claimed is:

1. A method of forming a field effect transistor comprising the following steps:

forming first and second source/drain blocks comprising conductively doped polysilicon;

forming a polysilicon layer overlying the source/drain blocks, the polysilicon layer comprising a first thickness and comprising first and second active areas electrically interconnected with the respective first and second source/drain blocks to define composite first and second transistor active regions having a second thickness greater than the first thickness, the polysilicon layer further comprising an intervening region between the first and second active regions, the intervening region having a thickness equal to the first thickness, the first and second source/drain blocks comprising uppermost surfaces; and

forming a top transistor gate over the intervening region, the top transistor gate extending to elevationally below the uppermost surfaces of the first and second source/drain blocks and extending over only one of the first and second source/drain blocks.

2. A method of forming a field effect transistor comprising the following steps:

forming first and second source/drain blocks;

forming a polysilicon layer overlying the source/drain blocks, the polysilicon layer comprising a first thickness and comprising first and second active areas electrically interconnected with the respective first and second source/drain blocks to define composite first and second transistor active regions having a second thickness greater than the first thickness, the polysilicon layer further comprising a channel region between the first and second active regions, the first and second source/drain blocks comprising vertically extending sidewall surfaces proximate the channel region;

forming a dielectric layer over the source/drain blocks and over the channel region, the dielectric layer comprising first and second vertically extending sidewall surfaces along the sidewall surfaces of the first and second source/drain blocks, respectively; and

forming a top transistor gate over the channel region, the top transistor gate contacting one of the dielectric layer first and second vertically extending sidewall surfaces, and the top transistor gate extending to a level elevationally below the uppermost surfaces of the first and second source/drain blocks and not contacting the other of the dielectric layer first and second vertically extending sidewall surfaces.

3. The method of claim 1 wherein the polysilicon layer is in situ conductively doped.

4. The method of claim 1 wherein the polysilicon layer is conductively doped subsequent to its formation.

5. The method of claim 2 wherein the polysilicon layer is in situ conductively doped.

6. The method of claim 2 wherein the polysilicon layer is conductively doped subsequent to its formation.



UNITED STATES PATENT AND TRADEMARK OFFICE  
**CERTIFICATE OF CORRECTION**

PATENT NO. : 6,235,562 B1  
DATED : May 22, 2001  
INVENTOR(S) : Charles H. Dennison et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 4,

Line 16, replace "about" with -- above --.

Line 64, replace "gated film" with -- gated thin film --.

Signed and Sealed this

Eleventh Day of December, 2001

*Attest:*

*Nicholas P. Godici*

*Attesting Officer*

NICHOLAS P. GODICI  
*Acting Director of the United States Patent and Trademark Office*